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ENGINEERING FEATURES OF THE SAN FERNANDO EARTHQUAKE

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INTRODUCTION

At 6 a. m. Tuesday, February 9, 1971, the strongest earthquake to strike metropolitan Los Angeles in this century occurred in the northern San Fernando Valley. The magnitude 6·6 earthquake was not a large earthquake in the seismological sense; earthquakes of this magnitude occur at an average rate of 30-40 per year on the earth, and on the average of about once every four years in the southern California area. From the engineering point of view, however, the earthquake was a very large and important one because it was located at the edge of a densely populated urban area and the region of heaviest ground motion contained an unusually large number of such critical installations as hospitals, dams, electrical switching and converter stations, freeway interchanges. Some 400,000 people were subjected to very strong ground shaking, and an additional 2,000,000 to moderately strong motion. Furthermore, the particular type of overthrust faulting that occurred resulted in a release of earthquake energy at an unusually shallow depth. Many of the heavily damaged facilities were virtually right on top of the earthquake and were subjected to severe shaking.

The estimated cost of the damage caused by the earthquake is in the vicinity of one-half billion dollars.

SUMMARY OF THE EFFECTS OF THE EARTHQUAKE

The major loss of life occurred at the Veterans Hospital in Sylmar where a concrete frame, tile-wall, pre-earthquake code, hospital building collapsed, killing 44. Another 11 were killed elsewhere, including two crushed by a collapsed freeway overpass, and an additional 9 were reported to have died from heart attacks. Four major facilities in the central region of the shock suffered severe damage: the new Olive View Hospital (initial cost $27 million); the Sylmar Converter Station of the Pacific Intertie (this large electrical switching and rectifying station had an initial cost of about $ 110 million); the Metropolitan Water District's new, large underground reservoir; and two earth dams at the Van Norman reservoir site (constructed 1915-1928).

There was also severe damage from ground movements to the six and one-half million dollar San Fernando Juvenile facility and vibrational and ground-movement damage to numerous one-and two-story industrial and commercial buildings in the San Fernando Valley. Some buildings in the eight-to fifteen-story range in North Hollywood suffered structural damage. In addition to the Veterans Hospital at Sylmar and the Olive View Hospital, the Pacoima Lutheran Hospital, the Holy Cross Hospital and the nearby Indian Hills Medical Center (an office building) all received serious structural damage. The most severe industrial damage occurred near Newhall where a glass factory suffered approximately $10 million damage. Nonstructural damage, including broken glass, fallen light fixtures and ceilings, and plaster cracking occurred throughout the San Fernando Valley and also in the adjoining areas of Glendale, Pasadena, Los Angeles, and to the north at Newhall and Saugus.

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An estimated $30 million damage was done to bridges and overpass structures on the Golden State, Foothill, San Diego and Antelope Valley freeways. Particularly hard hit were the interchange between the Golden State and Antelope Valley freeways and the interchange between the Foothill freeway and the Golden State freeway. Bridges on the Antelope Valley and Foothill freeways in the epicentral area also received serious damage.

Permanent ground displacements caused extensive disruption to underground utilities in parts of the San Fernando Valley, especially where surface faulting occurred. Gas lines were ruptured in several areas and water and sewer lines also were fractured affecting service to thousands of homes. Telephone service was lost to ten to twenty thousand customers in the epicentral area from approximately 4.5 million dollars damage to General Telephone's central facility in Sylmar. Emergency communications were hampered by a power outage at police headquarters and by destruction of the radio facility at the Veterans Hospital.

The faulting and the ground movement, combined with the shaking, damaged thousands of homes and hundreds were damaged to the point where they no longer could be occupied. Chimney damage was the most common vibrational damage and occurred as far away as Pasadena.

Old weak buildings in downtown San Fernando and as far away as Pasadena, Los Angeles and Santa Ana suffered significant damage, usually in the form of falling masonry. Two people were killed by failure of old buildings in downtown Los Angeles. Caltech's oldest building, Throop Hall, suffered extensive cracking to the nonstructural tile filler walls and to the exterior facing. Although no structural damage occurred in this earthquake, Throop Hall falls well below modern standards, and its eventual fate has not yet been decided.

Although the earthquake damage was severe, there were several factors which limited the disaster the earthquake might have caused. First, the area subjected to the most damaging shaking was of small size, and it was immediately adjacent to a relatively undamaged urban area containing extensive fire, police, medical and other service facilities. These services were adequate to cope with the situation without becoming seriously overloaded.

A second fortunate factor was that most people were in their homes at the time of the earthquake, and the type of residential construction common here is highly resistant to earthquake destruction. The typical light and strong wood frame house may be seriously cracked and damaged, but it seldom collapses completely with a major threat to life and limb. Only a very few, perhaps two or three, people were killed in their homes during this earthquake. If the shock had occurred just three hours later, the collapsed Psychiatric Day Care Center at the Olive View Hospital would have been occupied, the freeway overpasses would have collapsed on lanes of traffic and the falling debris from old buildings in San Fernando and Los Angeles would have pelted busy sidewalks. The resulting casualty toll would have been much more severe.

Another favorable factor was the lack of major landslides in densely populated areas. Such slides were a major source of damage in the Alaskan earthquake of 1964 and in the 1970 Peruvian earthquake, in which one major rock and ice avalanche buried two towns with an estimated 20,000 deaths. Fortunately, the possibility of such slides in the Los Angeles area seems small.

By far the most fortunate escape from disaster was the survival of the two Von Norman dams which were both severely damaged by the earthquake. The dams very nearly failed, and had the ground shaking lasted a little longer or had it been a little stronger, a catastrophic flood would have swept through a densely populated region before inhabitants could have been evacuated. This is perhaps the most frightening aspect of this earthquake.

On the positive side, the earthquake provided a large amount of valuable data on ground and building motions that will notably increase engineering knowledge of earthquakes. Some 200 accelerographs recorded earthquake motions at various locations on the ground, in buildings, on dams, etc. These accelerographs, maintained by NOAA's National Ocean Survey and Caltech's Earthquake Engineering Research Laboratory, provided by far the greatest amount of strong-motion data so far recorded in any earthquake. Included in these results is the strongest ground shaking ever recorded. The record was obtained in the middle of the epicentral region on a steep rock ridge near the south abutment of Pacoima Dam. The concrete arch dam was not damaged.

The large collection of records obtained in the earthquake is extremely valuable from the point of view of research. For the first time there is enough data on the character of the ground motion and the response of structures of strong shaking to begin to answer some of the fundamental questions in earthquake engineering research. Such questions include how much the local geology affects ground motion ; and what level of energy dissipation occurs in buildings under strong shaking.

LESSONS FROM THE EARTHQUAKE

The information gained from the San Fernando earthquake will aid greatly in efforts to reduce the disaster potential of future strong earthquakes. Many detailed studies are now underway to clarify particular features of the earthquake damage and to recommend ways to avoid damage in future shocks. Detailed recommendations and conclusions must await the results of careful study, but some general lessons of the earthquake are already apparent.

(1) A striking consequence of the earthquake was the fact that four hospitals in the San Fernando area were damaged so severely that they were no longer operational just when they could be needed most. Certain critical structures should be designed so that they remain functional after experiencing the most severe ground shaking. Included are hospitals, schools, high-occupancy buildings, buildings housing police and fire departments and other agencies relied upon to cope with disasters. In addition to the structures, emergency communication systems of these agencies must receive special care so they will not be damaged. Basic utilities that must be depended upon for the life of the community must also receive an extra measure of protection.

Ordinary building codes cannot be depended upon to preserve these functions, and special code provisions are necessary.

(2) This earthquake has provided the first really comprehensive practical test of U. S. earthquake codes. Modern structures designed according to the earthquake requirements of the building code performed well in the regions of moderately strong ground shaking. In the region of very strong ground motion, however, some modern buildings were severely damaged and the few that collapsed would have caused many additional deaths had they been occupied at the time. If the duration of strong ground shaking had been appreciably longer, as it would be in a great earthquake, some of the severely damaged structures would almost certainly have collapsed. It is clear that existing building codes do not always provide adequate safety against collapse, and such codes should be reviewed in detail and updated to include the latest practical developments in earthquake engineering.

(3) Many old, weak buildings in the regions of strong and moderately strong shaking suffered severe damage, and the major loss of life occurred in one old building designed before the adoption of modern building codes. There are many thousands of such old buildings in California that will collapse if subjected to strong ground shaking. Programs should be undertaken to render such buildings safe, or to raze them, over a reasonable period of time. A successful effort of this type has been underway for some time in the City of Long Beach, and in the City of Los Angeles especially hazardous parapet walls on several thousand buildings have been removed or strengthened. The San Fernando earthquake dramatically demonstrated the value of such procedures. A much more extensive program to eliminate the major hazards of old buildings is needed.

(4) The near catastrophic failure of the lower Van Norman dam endangered the lives of tens of thousands of people. Such risks are clearly unacceptable. A program for bringing older dams up to modern safety standards is imperative because many existing dams in all parts of the country have not been designed to resist earthquake forces. Such structures should be thoroughly examined and measures taken to reduce such hazards to an acceptable level. The successful performance of a new earth-fill dam at the Van Norman site shows that modern earthfill construction can withstand the earthquake forces that damaged the older dams.

(5) A number of freeway overpass bridges collapsed causing two deaths and resulting in major disruptions of traffic. In a great earthquake, such interruptions of transportation could greately magnify the disastrous effects of the earthquake. Freeway bridges, and important highway bridges, should be designed for adequate safety against collapse. Present standard code requirements for earthquake design of highway bridges are inadequate and should be revised in conformity with the current state of knowledge in earthquake engineering.

(6) It is noteworthy that school buildings in the region of strong shaking designed and constructed under the Field Act of the California State Legislature did not suffer structural damage that would have been dangerous to the occupants had the schools been in session. This demonstrates that one-and two-story school buildings can indeed be made safe by practicable code requirements even when subjected to every strong shaking combined with appreciable ground deformations beneath the structures. On the other hand, older school buildings that did not meet the requirements of the Field Act suffered potentially hazardous damage in regions of only moderately strong ground shaking. The lesson is clear that such hazardous school buildings must be eliminated or strengthened.

(7) None of the tall buildings in Los Angeles was seriously damaged by the earthquake, but it should be emphasized that this earthquake was too far away from downtown Los Angeles to be a good test of the strength of these structures. Tall buildings, like other buildings, can be made to resist to strongest shaking without collapse, but this does not occur automatically. Unless the special care devoted to the design of recent tall buildings is continued in the design of others, tall buildings, too, can be a hazard in the event of strong shaking.

(8) The extensive damage to electrical transmission facilities shows that the earthquake-resistant design of these facilities must be markedly improved. It has been estimated that it will be at least a year before repairs are completed at the Sylmar Converter Station, which suffered approximately $ 30 million damage.

(9) The approximate damage cost of $ 500 milion and the effects on vital services from a moderate earthquake occurring on the fringe of the Los Angeles metropolitan area point out the large disaster potential of major earthquakes. If the shock had

occurred near the center of the city, or if a great earthquake should occur on the San Andreas fault, it would seem that the damage could approach three or four billion dollars, and essential services would be severely crippled. The rapid recovery from the San Fernando earthquake showed that the disaster was not too large for the recuperative powers of the metropolitan area to overcome : the utilities, medical and protective systems handled the increased burden very well, and relative normalcy has been approached in a matter of days or weeks. It is not expected, however, that such systems could overcome the consequences of a great earthquake without major assistance from outside the metropolitan area.

(10) The San Fernando earthquake again demonstrated that the most practical approach to the problem of safety in earthquakes is earthquake-resistant design. Structures can be designed to withstand safely the most severe earthquakes, but this cannot be done without an increase in cost. For many buildings, and other structures, this increase in cost is a modest one ; for others it may represent a significant increase in overall investment. Once essential function and safety of life and limb has been assured, the problem of earthquake-resistant design becomes an economic problem ; the initial cost must be balanced against the possible cost of repair to earthquake damage over the expected lifetime of a structure.

The San Fernando earthquake, though a disaster to many, has provided a unique opportunity to learn about the effects of strong earthquake motion. The results of the many engineering studies now underway, and the actions and regulations prompted by this earthquake should reduce significantly the hazard from earthquakes of the future.

The following figures show some of the earthquake damaged structures.

Fig. 1. Aerial Photo of Freeway Interchange

This aerial view shows a portion of the interchange between the Foothill and Golden State Freeways. Nearly every bridge and overpass structure in the interchange was seriously damaged by the earthquake.

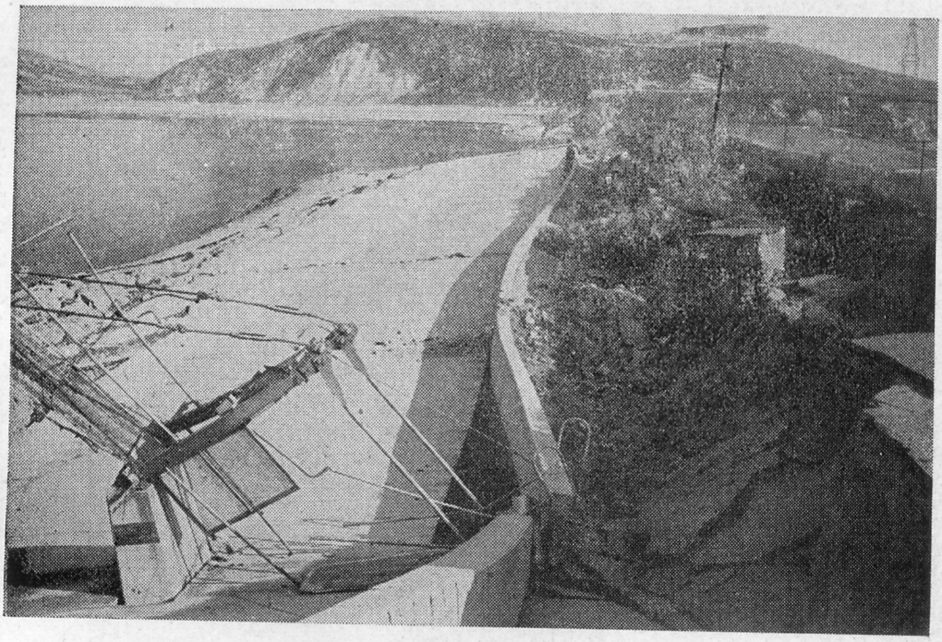

Fig. 2. Lower Van Norman Dam

This aerial view of the Lower Van Norman Lake on the day of the earthquake shows the spectacular damage to the earth-fill dam. A major section of the dam slid into the reservoir in an arcuate slide, leaving a scarp of some five feet between the water level and the top of the remaining portion of the dam. The cracks forming on the lower face of the dam, to the left, are incipient slides and show how near the catastrophe actually was. If the period of intense shaking had lasted somewhat longer, the dam would surely have given way. Both the lower and upper Van Normal dams, built in the 1910's and 1920's were damaged, but a new earth dam, located on the same site, survived the shock with no apparent structural damage.

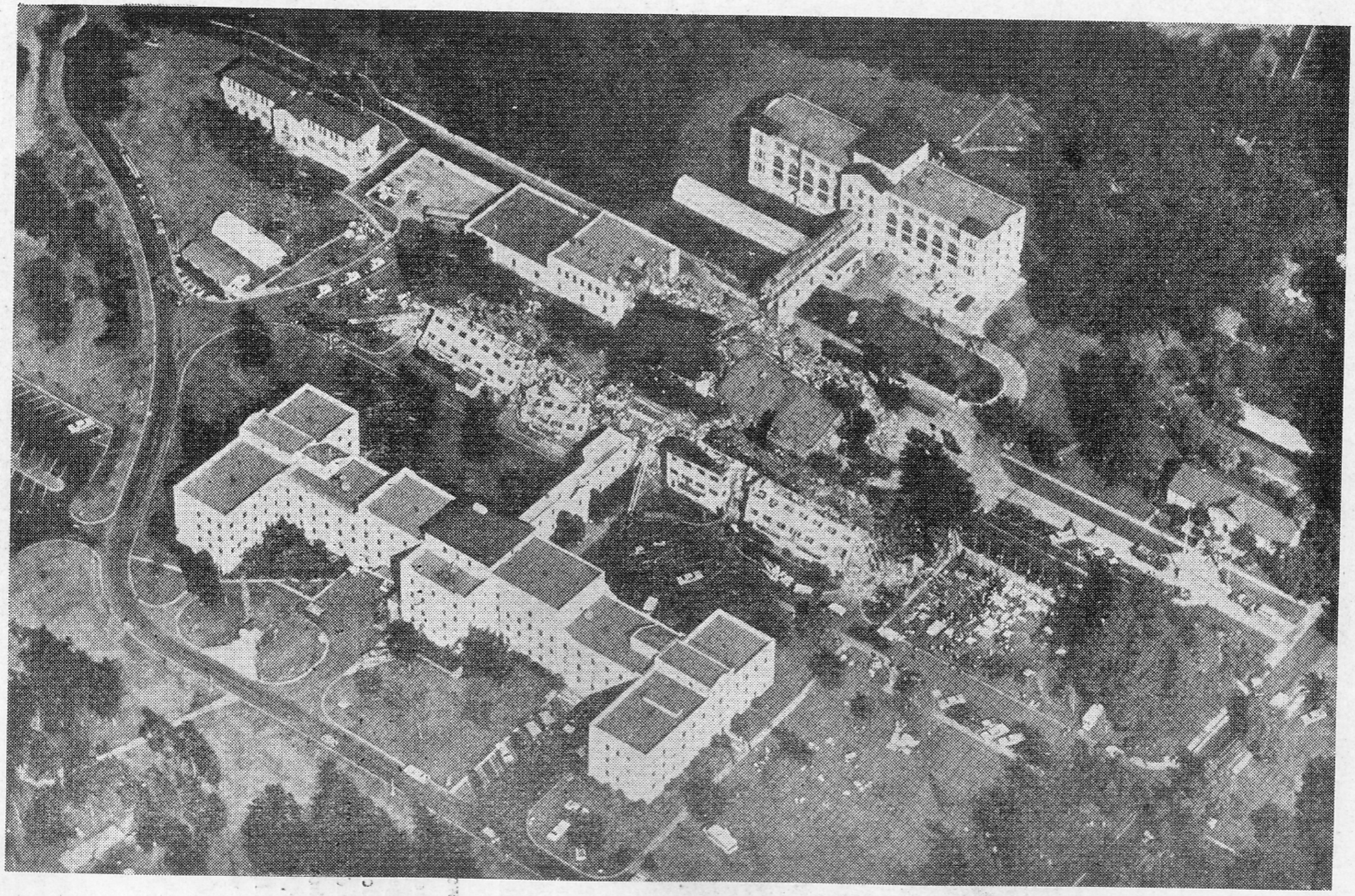

Fig. 3. Aerial Photo of V. A. Hospital

Taken the day of the earthquake, this photo looks approximately northward over the V. A. Hospital in Sylmar. The collapsed structures, seen in the center of the photograph, were both built in 1926 before earthquake-resistant design procedures were embodied in the building codes. The adjacent major structures were built in 1937 and 1947 and received no significant structural damage.

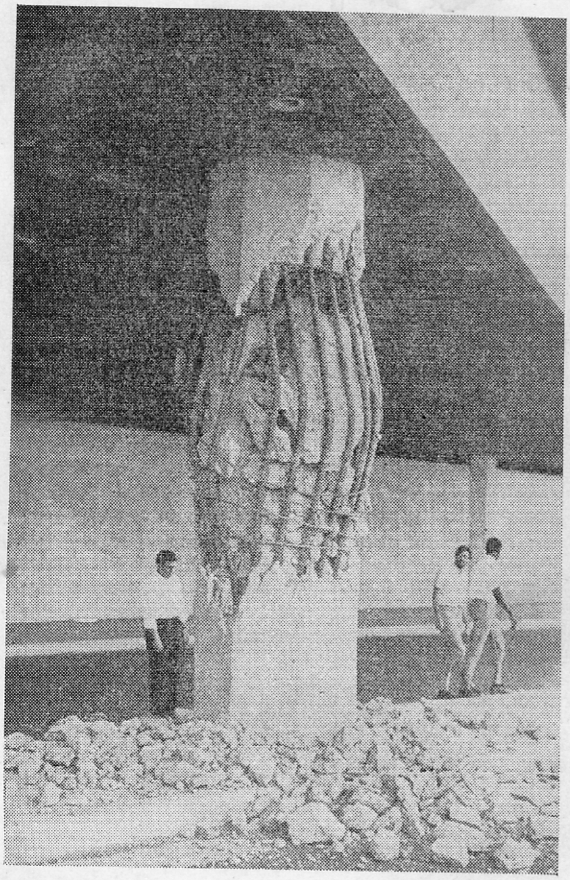

Fig. 4. Demaged columns on the Foothill Boulevard overcrossing of the Foothill Freeway. The complex failure of the bridge was aggravated by the inadequate ties confining the 2-1/4-inch diameter main reinforcing steel.

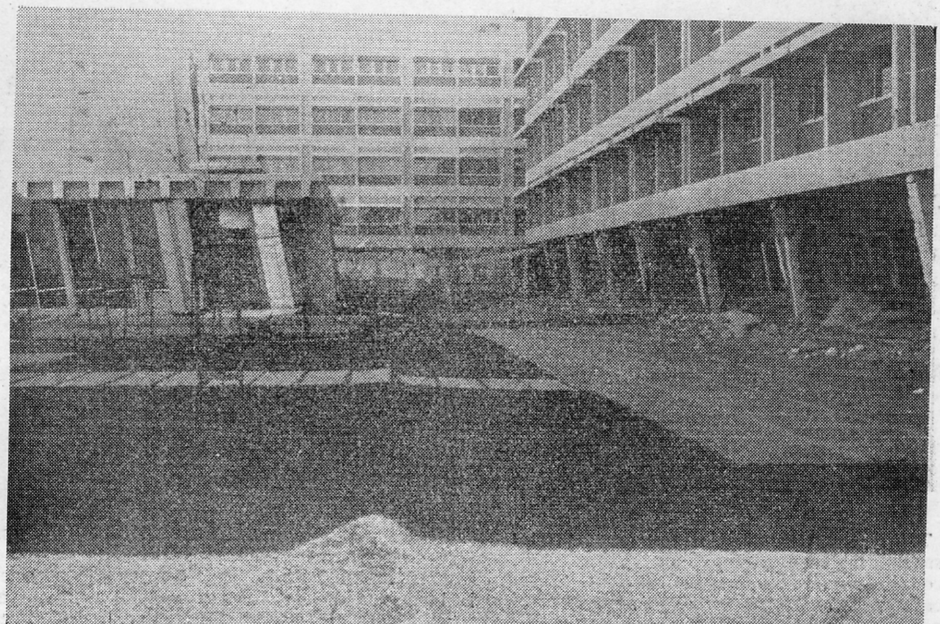

Fig. 5. This view of the Olive View Hospital, looking east, shows a closeup of the column failures. The corner column is a tied column; the side columns are spirally reinforced and performed much better. The small one-story structure at the left is the auditorium. It shows a failure of the connection between the roof and the supporting columns. In the foreground at far right can be seen the bottom of one of the five-story end sections which failed at its framed support and toppled into the basement.

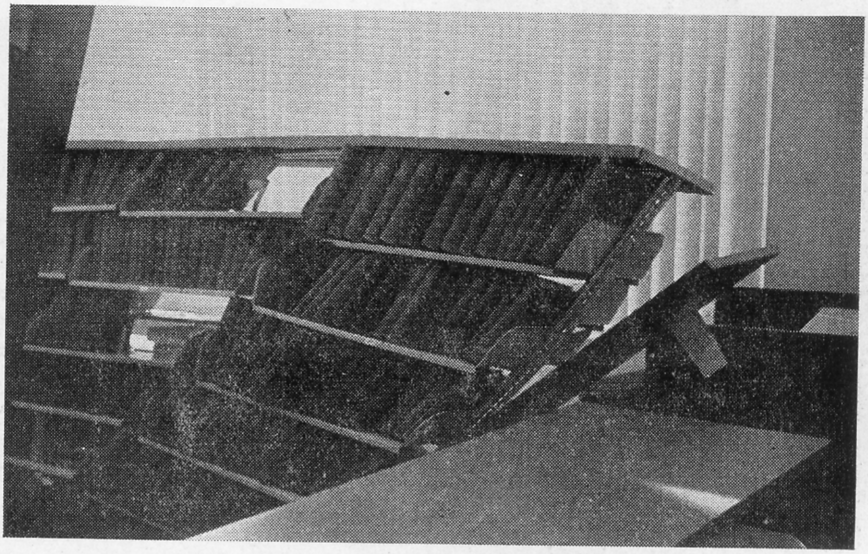

Fig. 6. Nearly all of the bookshelves on the upper floors on the east side of Millikan Library collapsed, and some bookshelves failed as far down as the second floor. The accelerograph at the base of the library recorded a maximum acceleration of 15%g and the instrument at the top showed about 35%g. All told, some 75,000 of 200,000 volumes were spilled to the floor.

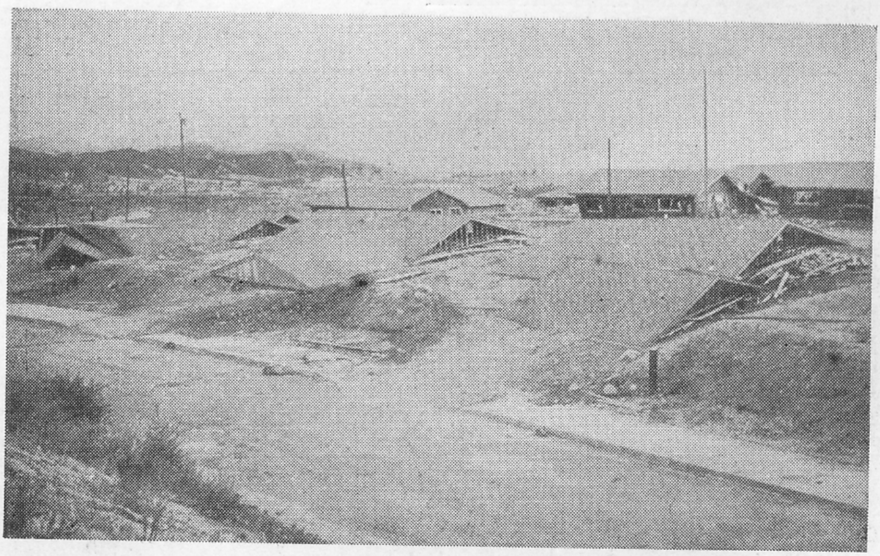

Fig. 7. The typical southern California wood frame house, light in weight, and relatively strong, is normally safe during earthquakes. The homes in this picture, taken in a residential subdivision in the Pacoima Canyon area, were in various stages of construction. Those in front which completely collapsed were at the framing stage. Those in the background were covered outside with tarpaper and wire mesh preparatory to stuccoing. One or two homes, not visible in this picture, had already been stuccoed, and these survived without failure.